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Lecture 6

Mechanisms of Solute Transport Across Plasma Membranes

- **Passive absorption of mineral salts**
- **Active absorption of mineral salts**

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Mechanisms of Solute Transport Across Plasma Membranes

Previously it was thought that absorption of mineral salts takes place along with water absorption, but it is now understood that mineral salt absorption and water absorption are two different processes. Mineral salts are absorbed from the soil solution in the form of ions. They are chiefly absorbed through the meristematic regions of the roots near the tips.

Plasma membrane of the root cells is not permeable to all the ions. It is selectivity permeable. All the ions of the same salt are not absorbed at equal rate but leads unequal absorption of ions. First step in the absorption of mineral salts is the process of Ion exchange which does not require metabolic energy.

The further processes of the absorption of mineral salts may be of two types.

- **Passive absorption of mineral salts**

a. Simple diffusion

When the concentration of mineral salts is higher in the outer solution than in the cell sap of the root cells, the mineral salts are absorbed according to the concentration gradient by simple process of diffusion. This is called as passive absorption because it does not require expenditure of metabolic energy.

b. Facilitated diffusion

Is the passage of molecules or ions across a biological membrane through specific transport proteins and requires no energy input. Facilitated diffusion is used especially in the case of large polar molecules and charged ions; once such ions are dissolved in water they cannot diffuse freely across cell membranes due to the hydrophobic nature of the fatty acid tails of the phospholipids that make up the bilayers. The type of carrier proteins used in facilitated diffusion is slightly different from those used in active transport. They are still transmembrane carrier proteins, but these are gated transmembrane channels, meaning they do not internally translocate, nor require ATP to function. The substrate is

taken in one side of the gated carrier, and without using ATP the substrate is released into the cell.

c. Ion exchange

The ions adsorbed on the surface of the plasma membrane of the root cells may be exchanged with the ions of same sign from external solution for example the cation K^+ of the external soil solution may exchanged with H^+ ions adsorbed on the surface of the plasma membrane. Similarly anion may be exchanged with OH ions. There are two theories regarding the mechanism of ion exchange.

1. **Contact exchange theory**

According to this theory the ions adsorbed on the surface of root cells and clay particles are not held tightly but oscillate within small volume of space. If the roots and clay particles are in close contact with each other, the oscillation volume of ions adsorbed on root surface may over by the oscillation volume of ions adsorbed on clay particles, and the ions adsorbed on clay particle may be exchanged with the ions adsorbed on root surface directly without first being dissolved in soil solution.

2. **Carbonic acid exchange theory**

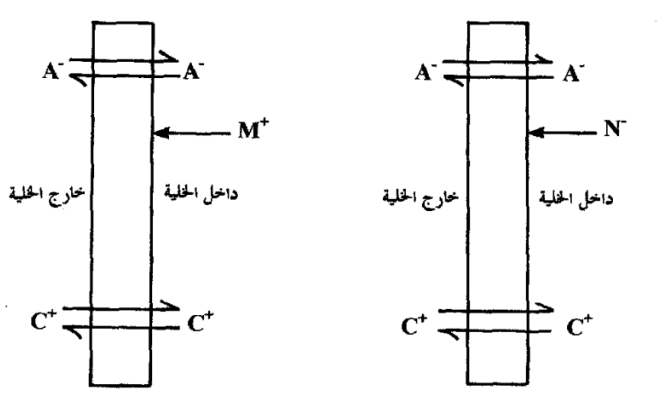
According to this theory, the CO_2 released during respiration of root cells combines with water to form carbonic acid (H_2CO_3). Carbonic acid dissociates into H^+ and an anion HCO_3 in soil solution. These H^+ ions may be exchanged for cations adsorbed on the clay particles. The cations thus released into the soil solution from the clay particles, may be adsorbed on root cells in exchange for H^+ ions or as in ion pairs with bicarbonate. Thus, the soil solution plays an important role in carbonic acid exchange theory.

d. Donnans' Equilibrium

The accumulation of ions inside the cells without involving expenditure of the metabolic energy can be explained to some extent by Donnan's equilibrium theory. According to this theory there are certain preexisting ions inside the cell which cannot diffuse outside through membrane. Such ions are called as indiffusible or fixed ions. However, the membrane is

permeable to both anions and cations of the outer solutions. Suppose there are certain fixed anions in the cell which is in contact with outer solution containing anions and cations. Normally equal number of anions and cations would have diffused into the cell through an electrical potential to balance each other, but to balance the fixed anions more cations will diffuse into the cell. This equilibrium is known as Donnan's equilibrium. In this particular case, there would be an accumulation of cations inside the cell. If however, there are fixed cations inside the cell, the Donnan's equilibrium will result in the accumulation of anions inside the cell

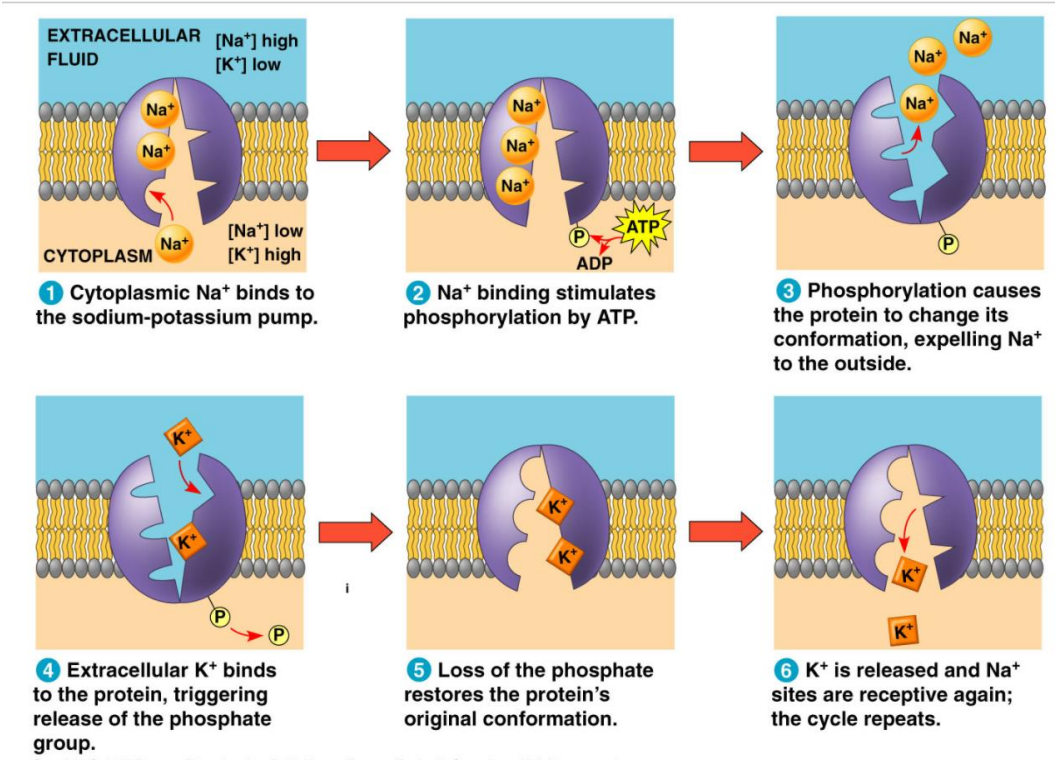
In sandy soils, the spaces between particles are so large that water tends to drain from them and remain only on the particle surfaces and at interstices between particles. In clay soils, the channels are small enough that water does not freely drain from them; it is held more tightly . The moisture-holding capacity of soils is called the field capacity. Field capacity is the water content of a soil after it has been saturated with water and excess water has been allowed to drain away.

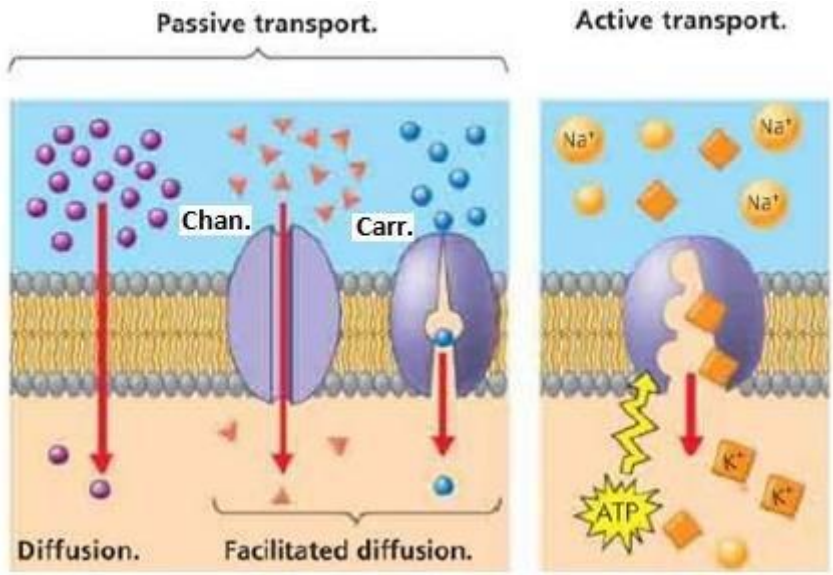


♦ Active absorption of mineral salts

Is the movement of a substance across a membrane against its concentration gradient. This is usually to accumulate high concentrations of molecules that a cell needs. The accumulation of mineral salts against to concentration gradient is an active process which involves the expenditure of metabolic energy through respiration. The active absorption of mineral salts involves the operation of a carrier compound present in the plasma membrane of the cells.

If the process uses chemical energy, such as adenosine triphosphate (ATP), it is called primary active transport. Secondary active transport involves the use of an electrochemical gradient, and does not use energy produced in the cell. Unlike channel proteins which only transport substances through membranes passively, carrier proteins can transport ions and molecules either passively through facilitated diffusion, or via secondary active transport. A carrier protein is required to move particles from areas of low concentration to areas of high concentration. These carrier proteins have receptors that bind to a specific molecule (substrate) needing transport. The molecule or ion to be transported (the substrate) must first bind at a binding site at the carrier molecule, with a certain binding affinity. Following binding, and while the binding site is facing the same way, the carrier will capture or occlude (take in and retain) the substrate within its molecular structure and cause an internal translocation so that the opening in the protein now faces the other side of the plasma membrane. The carrier protein substrate is released at that site, according to its binding affinity there. According to this theory, the plasma membrane is impermeable to free ions. But some compounds present in it acts as carrier and combines with ions to form carrier- ion- complex which can move across the membrane. On the inner side of the membrane this complex leaves releasing ions into the cell while the carrier goes back to the outer surface to pick up fresh ions. In primary active transport ; ions and molecules move against their concentration by using the energy provided by hydrolysis of ATP. First of all the ion or molecule binds to a carrier protein at binding site. ATP released by mitochondria is hydrolyzed forming ADP and Pi. This phosphate binds to the carrier protein which then changes its conformation (structure) a bit. The molecule or ion is thus transferred from its crowded area to the one with low concentration. And the bound phosphate then is released from carrier protein causing it to flip back to its previous shape. Example Sodium-potassium (Na+/K+) pump. They are two hypotheses based on the carrier concept to explain the mechanism of active salt absorption. Although they are not universally accepted.





1. Lundegardhs cytochrome pump theory

Lundegardh and Burstrom (1933) believed that there was a definite correlation between respiration and anion absorption. Thus when a plant is transferred from water to a salt solution the rate of respiration increases. This increase in rate of respiration over the normal respiration has been called as anion respiration or salt respiration. Lundegardh

(1954) proposed cytochrome pump theory which is based on the following assumptions.

1. The mechanism of anion and cation absorption is different

2. Anions are absorbed through cytochrome chain by an active process. (Cytochromes are ion – porphyrin proteins that act as enzymes and helps in election transfer during respiration).

3. Cations are absorbed passively.

According to this theory

1) Dehydrogenase reactions on inner side of the membrane give rise to protons (H^+) and electrons (e-).

2) The electrons travels over the cytochrome chain towards outside the membrane, so that the Fe of the cytochrome becomes reduced (Fe^{++}) on the outer surface and oxidized (Fe^{+++}) on the inner surface.

3) On the outer surface, the reduced cytochrome is oxidized by oxygen releasing the electron (e^-) and taking an anion (A^-).

4) The electron thus released unites with H^+ and oxygen to form water

5) The anion (A^-) travels over the cytochrome chain towards inside.

6) On the inner surface the oxidized cytochrome becomes reduced by taking an electron produced through the dehydrogenase reactions and the anion (A) is released.

7) As the result of anion absorption, a cation (M) moves passively from outside to inside to balance the anion.

2. Bennert – Clark's protein Lecithin Theory

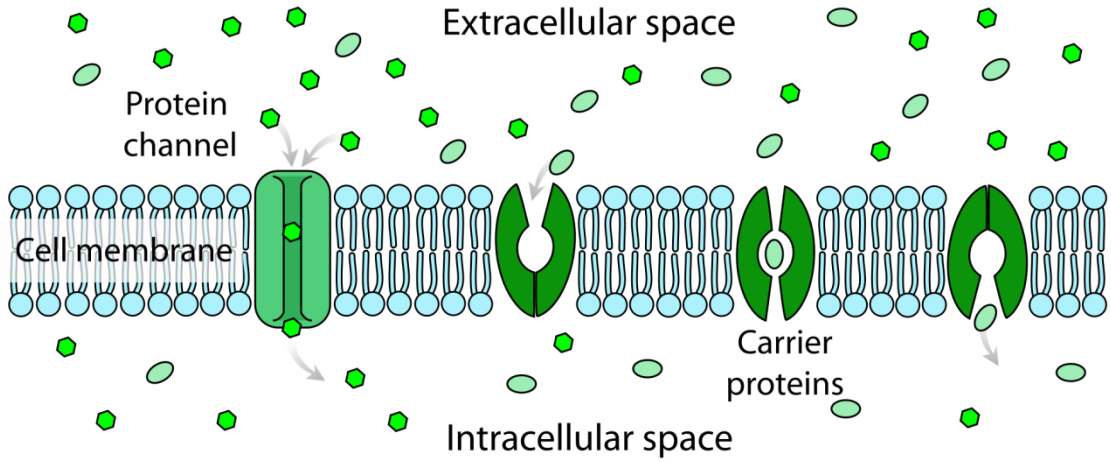
In 1856, Bennet – Clark suggested that because the cell membranes chiefly consist of phospholipids and proteins and certain enzymes seem to be located on them, the carrier could be a protein associated with the phosphatide called as lecithin. He also assumed the presence of different phosphatides to correspond with the number of known competitive groups of cations and anions. According to this theory

1. Phosphate group in the phosphatide is regarded as the active centre binding the cations and the basic choline group as the anion binding centre.

2. The ions are liberated on the inner surface of the membrane by decomposition of lecithin by the enzyme lecithinase.

3. The regeneration of the carrier lecithin form phosphatidic acid and choline takes place in the presence of the enzyme choline acetylase and choline esterase and ATP. The latter acts as a source of energy

- **Active transport is not the same as facilitated diffusion.** Both active transport and facilitated diffusion do use proteins to assist in transport. However, active transport works against the concentration gradient, moving substances from areas of low concentration to areas of high concentration. In addition, the types of proteins that they use are different. **Active transport uses carrier proteins, not channel proteins.** These carrier proteins are different than the ones seen in facilitated diffusion, as they need ATP in order to change conformation. Channel proteins are not used in active transport because substances can only move through them along the concentration gradient.



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